*Journal of Chemical and Natural Resources Engineering,Special Edition :1-7*


# REVIEW OF MIXTURE FORMATION UNIT FOR CNG MOTORCYCLE

R.MOHSIN[1], Z. YAACOB[2], Y.CHANG[3]

## ABSTRACT

The poor mixing homogeneity and air-fuel ratio controllability of the former mixture formation units for a CNG motorcycle are deemed to be the culprits of its lethal exhaust emissions and poor engine performance. In this research, the fuel system of a CNG powered motorcycle, focusing on the mixture formation unit was reviewed. Owing to the significant benefits of the single-point-injection-type (SPIT) system over the mixer-type (MT) system, attempts to develop a mixer with the SPIT system, i.e. Throttle Body Injection Mixer (TBIM), was conducted through Computational Fluid Dynamics (CFD) modelling. CFD results revealed a significant improvement of mixing homogeneity in TBIM.

***Key Words:*** Mixer-type (MT), Single-point-injection-type (SPIT), Throttle Body Injection Mixer (TBIM), Computational Fluid Dynamics (CFD) modelling.

## 1.0 INTRODUCTION

Inline with the rapid industrialization and urbanization, air pollution has become part and parcel of modern-day living when impure or harmful substances are released into the atmosphere. Among all the main sources of air pollution, motor vehicles have been asserted as the chief culprits of the health hazard and environmental problems owing to their lethal exhaust emissions. Esther [1] claimed that 82.54 percent of the air pollution was attributed to the emissions of motor vehicles, while 8.78 percent by the power station and 8.48 percent by the industries.

Strong pressure for reduction in automotive exhaust emissions in municipal areas, for instance Kuala Lumpur and Johor Bahru, has prompted local governments and other bodies to promote the use of low-emission vehicles that utilize alternative fuels. Amongst such vehicles, those that run on compressed natural gas (CNG), called CNG vehicles, are catching the fancy of local governments and some associated bodies like Petronas NGV Sdn. Bhd. Apart from the abundant resource of natural gas itself, one of the attractive features of CNG vehicles is the significant reduction of exhaust emissions for pollutants such as particulate materials (PM), carbon monoxide (CO), nitrogen oxide ($NO_x$) and photochemically reactive hydrocarbons as compared to the use of petroleum-based fuels [2]. Table 1 shows the cumulative figures of CNG vehicles and refuelling stations in Malaysia over the past few years [3]. Petronas NGV Sdn. Bhd. targets to have a total of 94 CNG refueling outlets around the country capable of serving about 57,000 natural gas vehicles by the year 2009 [3].

Nowadays, CNG vehicles available in Malaysia are mostly sedans, which are of four-wheeler. CNG vehicles of two-wheeler like motorcycles and scooters are still rarely seen. Nevertheless, the need to develop a CNG powered motorcycle was perceived when

[1,2]Department of Gas Engineering, Faculty of Chemical and Natural Resources Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Malaysia.
[3]Department of Chemical Engineering, Universiti Teknologi PETRONAS Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia.
Correspondence to : Rahmat Mohsin (rahmat@fkkksa.utm.my)

Ishak [4] claimed that motorcycles accounted for approximately 50 percent of the total number of registered vehicles in Malaysia. This implies that motorcycles have a tendency to contribute greatly to the emission problem caused by motor vehicles. Therefore, a CNG powered motorcycle, which possesses cleaner burning characteristics, was developed to curb the emission problem.

On the whole, there are three main features or components that determine the performance of an engine: combustion system, fuel system and catalyst technology [5]. In the present work, the fuel system of a CNG powered motorcycle, focusing on the mixture formation unit was reviewed.

**Table 1** Growth of CNG vehicles and refuelling stations in Malaysia

| Financial Year | CNG Vehicles | CNG Refuelling Stations |
|---|---|---|
| 2000/2001 | 3980 | 19 |
| 2001/2002 | 5470 | 24 |
| 2002/2003 | 7191 | 31 |
| 2003/2004 | 10329 | 36 |
| 2004/2005 | 12766 | 38 |
| 2005/2006 | 14700 | 39 |

*(Source: The financial year of Petronas NGV Sdn. Bhd. is from April 1st of one year to March 31st of another year)*

## 2.0 METHODOLOGY

### 2.1 Fuel System of CNG Vehicles

Figure 1 shows the outline of a conventional CNG fuel system. Three major components of the fuel system include the CNG storage container, air-fuel mixer and the pressure regulator. On the whole, CNG is brought in at high pressure gaseous form from the storage container, passing through the single- or multiple-stage pressure regulator, and finally to the air-fuel mixer before entering the engine [5].

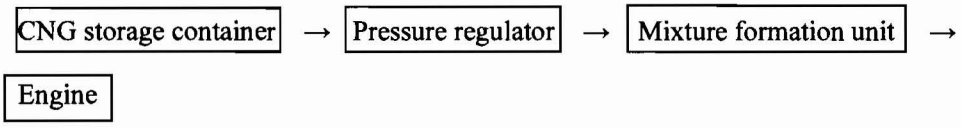


**Figure 1** Outline of conventional CNG fuel system

### 2.2 Types of Mixture Formation Unit

Mixture formation unit is a system where fuel is metered and mixed with the incoming air into the cylinders in accordance with engine requirements. Depending on its configuration within the engine, the mixture formation unit can be divided into two categories, i.e. the single- and multi-point mixture formation units [6].

The single-point mixture formation unit is arranged centrally in the engine, where it feeds the fuel to the air flowing into the cylinders at one point [6]. In other words, all

cylinders are served by one unit. As for the multi-point mixture formation unit, instead of feeding the fuel into all cylinders at one point, the fuel is fed individually for each cylinder. Consequently, the multi-point arrangement does not exhibit problem of unequal fuel distribution in the intake manifolds, which in contrast, is a recurring source of predicaments in the single-point arrangement [7].

A single-point arrangement mixture formation unit was selected in the present work. Since the CNG motorcycle used was of single-cylinder engine with only one intake manifold, qualms of uneven fuel distribution inherent in the single-point arrangement could be neglected. There are two types of single-point arrangement: the mixer-type (MT) and the single-point-injection-type (SPIT). The primary difference between these two types is their fuel supply system, in which the former type is of mechanical fuel controlled whereas the latter type is of electronic fuel controlled [8].

## 2.3 Advantages and Disadvantages of Mixer-Type System

The advantages of MT system are outlined as follows [6, 7]:

i. *Simple device*: It has a simple structure with minimum moving or bearing surfaces.
ii. *Little maintenance is required*: Since it has minimum moving or bearing surfaces, it requires only little maintenance.

iii. *Inexpensive die-cast and stamped parts*: Experience of mass production over the past few years has dictated its inexpensive die-cast and stamped parts.

Nevertheless, there are some remarkable disadvantages of MT system which are outlined as follows:

i. *Poor controllability of air-fuel ratio*: The main weakness of MT system seems to be associated with the finite response of mixer, which is attributed to the use of air flow dependent vacuum signal strength for control [8]. As a result, it is difficult to synchronize, i.e. to adjust to identical throughputs of air and fuel.

ii. *Unsatisfactory performance of feedback system*: To improve the air-fuel ratio controllability, an MT system is normally integrated with a feedback system. However, Klimstra [8] discovered the unsatisfactory performance of feedback system in controlling the air-fuel ratio at different engine operating modes. They found that the output of exhaust gas oxygen sensor was usually affected by several time delays. This caused the electronic controller of feedback system to respond relatively slow to disturbances.

## 2.4 Advantages of Single-Point-Injection-Type over the Mixer-Type System

A SPIT system is a device which possesses one (or more) injector that is normally located downstream of the throttle valve to take full advantage of the mixing effects [7]. The advantages of a SPIT system compared to an MT system (with a feedback system) are outlined as follows [5, 6]:

i. *Simpler structure*: Unlike the MT system, which is usually rather complex and consists of several units, a SPIT system has a simpler structure. It can replace the MT system by just installing one electronic injector to the system.

ii. *Lower equipment cost*: Since a SPIT system utilizes only one injector, it has a relatively lower equipment cost than the MT system.

iii. *Greater flexibility of manifold design*: With a simpler configuration, which merely replaces the MT system by an electronic injector, a SPIT system provides greater flexibility of manifold design with, in some cases, reduction of overall engine height.

iv. *Much better air-fuel ratio controllability*: A SPIT system can achieve more precise control of mixture strength (relative air-fuel ratio) that is called for by the most satisfactory methods of pollution reduction. It permits more accurate matching to the requirements of the engine through a computer control of delivery. Unlike the MT system, which requires many corrections despite the integration of feedback system, a SPIT system is able to deliver the exact amount of fuel required at different engine operating modes. The amount of fuel needed is determined by an electronic control unit before delivering it through an injector. Consequently, it is able to control the air-fuel ratio more efficiently than the MT system.

v. *Allows more reduction of pressure drop*: As compared to the MT system, a SPIT system allows more reduction of pressure drop from atmosphere to manifold. This results in the consequent gain of power and torque.

Due to the significant benefits of SPIT system as compared to MT system, attempts to develop a mixer of SPIT system for a single-cylinder CNG motorcycle, namely throttle body injection mixer (TBIM), was conducted in this research.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Mixers for Compressed Natural Gas Motorcycle

#### 3.1.1 The First and Second Generations of Mixers

Ever since the advent of the first CNG powered motorcycle by Yaacob *et al.*[9] sustained research and work, particularly on the fuel system, has been carried out to enhance the engine performance. The mixer, which has hitherto undergone three generations, still exhibits some drawbacks and further improvement is required. Since the design of the first generation of mixer (Figure 3) did not conform to the dynamic of the fluid flow structure, its air-fuel mixing did not fulfil the basic principle of efficient combustion, i.e. homogeneous mixing [10]. With the emergence of the second generation of mixer (Figure 4), even though the homogeneity of air-fuel mixing had been improved, difficulties in the air-fuel ratio control had offset its performance [11]. Both the first and second generations of mixers were of mechanical fuel controlled.

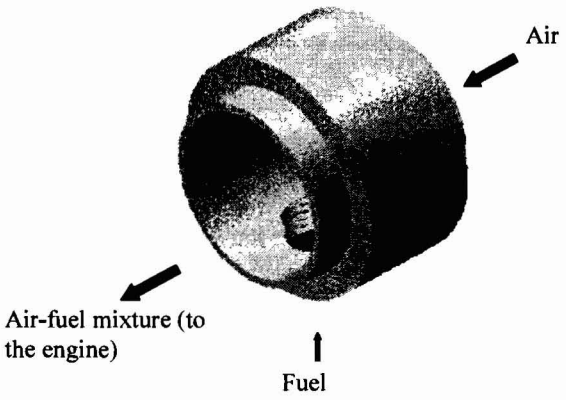


**Figure 3** First generation of mixer for CNG motorcycle [10]

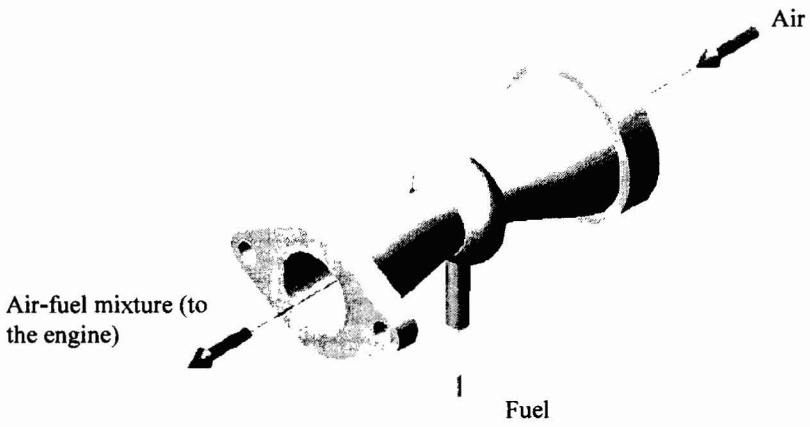


**Figure 4** Second generation of mixer for CNG motorcycle [11]

### 3.1.2 The Third Generation of Mixer

After being besieged by problems related to homogeneity and air-fuel ratio control, the third generation of mixer, i.e. Throttle Body Injection Mixer (TBIM) (Figure 5), which was of electronic fuel controlled, was developed in this research. With an electronic fuel controlled system, the overall mixing homogeneity and air-fuel ratio controllability of TBIM had been improved tremendously. This is shown by the single contour of mass fraction of methane obtained in TBIM through Computational Fluid Dynamics (CFD) modelling in Figure 6.

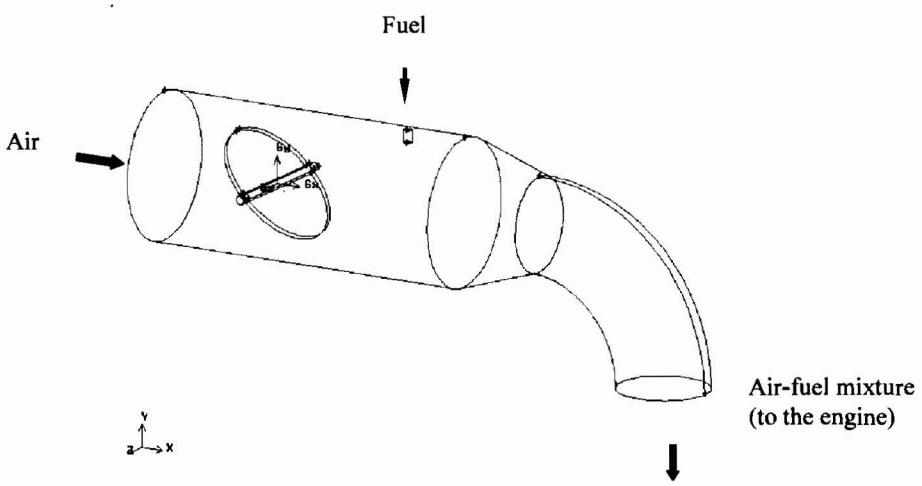


**Figure 5** Third generation of mixer (i.e. TBIM) for CNG motorcycle

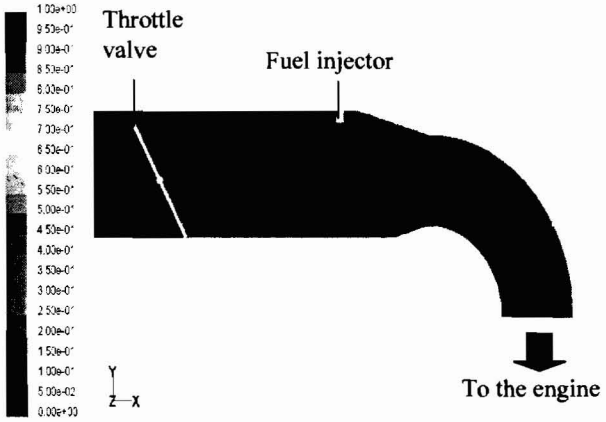


**Figure 6** Contours of mass fraction of methane in TBIM [12]

## 4.0 CONCLUSION

Mixture formation unit in the fuel system plays a significant role in determining the engine performance of CNG vehicles. It has both single- and multi-point arrangements. In the present work, the single-point arrangement was selected since the CNG motorcycle used is of single-cylinder engine with only one intake manifold. Nevertheless, the single-

point arrangement can be appeared in two different features, i.e. the MT and SPIT systems. Due to the significant benefits of SPIT system as compared to the MT system, attempts to develop a mixer of SPIT system for a single-cylinder CNG motorcycle, namely TBIM, was conducted through CFD modelling. With an electronic fuel controlled system, the overall mixing homogeneity and air-fuel ratio controllability of TBIM had been improved tremendously.

## REFERENCES


[1] Esther, T. (1999). Motorcycle Makers Welcome Move to Cut Emissions. *New Straits Times*, 14 December.

[2] Weaver, C. S. 1989. Natural Gas Vehicles – A Review of the State of the Art. *SAE Technical Paper Series*. SAE 892133.

[3] Petronas Financial Year Report. 2006. Malaysia: Petronas NGV Sdn. Bhd.

[4] Ishak, A. 2001. Urban Air Quality management: Motor Vehicle Emission Control in Malaysia. *Clean Air Regional Workshop Fighting Urban Air Pollution: From Plan To Action*. February 12-14.Department of Environment Malaysia: Paper No.18.

[5] Nylund, N. and A. Lawson. 2000. *IANGV Emission Report*. International Association for Natural Gas Vehicles. www.iangv.org (excess March 2004).

[6] Lenz, H. P., W.Bohme, H. Duelli, G. Fraidl, H. Friedl, B. Geringer, P.Kohoutek, G. Pachta, E. Pucher, and G. Smetana.1990. *Mixture Formation in Spark-Ignition Engines*. New York: Springer-Verlag Wien.

[7] Heywood, J. B. 1988. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill.

[8] Klimstra, J. 1987. Catalytic Converters for Natural Gas Fueled Engines – A Measurement and Control Problem. *SAE Technical Paper Series*. SAE 872165.

[9] Yaacob, Z., Z.A. Majid, M.P.I.P. King, and H.L. Ong. 1999. A Study on Exhaust Performance and Lubricating Oil Effects on Natural Gas Motorcycle. *Jurnal Teknologi*. 31(F).

[10] King, M.P. I. P. 1999. *Natural Gas Motorcycle*. Universiti Teknologi Malaysia. Malaysia: M. Eng. Thesis.

[11] Yeap, B.H. 2001. *Computational Investigation of Air-fuel Mixing System for Natural Gas Powered Motorcycle*. Universiti Teknologi Malaysia. Malaysia: M. Eng. Thesis.

[12] Chang, S. H. 2006. *Effect of Injection Characteristics on Throttle Body Injection Mixer for Compressed Natural Gas Motorcycle*. Universiti Teknologi Malaysia. Malaysia: M. Eng. Thesis.